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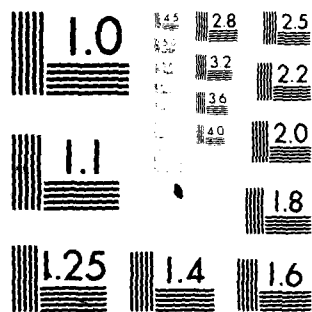
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## TECHNICAL REPORT

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EVALUATION OF THE PERFORMANCE OF A LASER FOR  
AIRBORNE DEPTH SOUNDING

D. REES and P.J. WILSEN

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EVALUATION OF THE PERFORMANCE OF A LASER FOR AIRBORNE DEPTH SOUNDING

D. Rees and P.J. Wilsen

S U M M A R Y

The performance of a conventional electro-optically Q-switched, frequency-doubled Nd:YAG laser is evaluated for a laser airborne depth sounder operating at 168 Hz. The laser more than meets the requirements of the depth sounder and successfully completed a 1000 hour lifetest.



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## 1. INTRODUCTION

A laser airborne depth sounder (LADS) is being developed at the Defence Research Centre Salisbury for use by the Royal Australian Navy in charting coastal waters. An overview of the LADS system and its performance is described by Calder(ref.1), and also Clegg and Penny(ref.2). A pulse transmission mode laser has been examined(ref.3) for its suitability in the LADS system but complications at high repetition rates, where thermal compensation becomes necessary, preclude its adoption. A recent comparison of crossed-Porro and a conventional resonator for the LADS(ref.4) showed that the crossed-Porro resonator has a short life expectation. The conventional resonator, with a high output coupling mirror, is more suitable.

The LADS has been using two conventional Q-switched lasers each operating at 42 Hz. Pump energies of between twelve and fifteen joules were required to obtain the specified output. The relatively high energy input to the flashlamp meant that its permitted maximum average power was exceeded at 80 Hz. This limited the repetition rate of the system.

Alterations to the pump cavity, a shortening of resonator length, and a more efficient frequency doubler, considerably improved the performance. This report is an evaluation of the revised laser for the LADS application.

## 2. LASER DESCRIPTION

A schematic diagram of the conventional Q-switched laser is shown in figure 1. The resonator length is 230 mm. The 3 mm diameter, 50 mm long, neodymium doped yttrium aluminium garnet (Nd:YAG) rod is pumped by a 4 mm bore, 50 mm arc length, high pressure krypton filled flashlamp. A flashlamp simmer current of 5 amperes is used to provide reliable jitter-free operation(ref.5). The flashlamp and rod centres are equally spaced about the centre of a small circular cylindrical pump cavity of 25 mm diameter. The separation between the centres of rod and flashlamp is 12 mm. The pump cavity reflector is polished stainless steel coated with evaporated gold.

A Glan-polariser, Pockels cell and quarter-wave plate are used for Q-switching. The transmission of the output mirror is approximately 90%, which keeps the energy within the resonator low, thus reducing the probability of optical damage to resonator components. The frequency doubler is a 10x10x30 mm, angle-tuned, cesium di-deuterium arsenate (CD\*<sub>2</sub>A) crystal cut for normal incidence at 50°C.

### 2.1 Laser specification

The specification for the LADS laser is shown in the following table:

532 nm output energy	5 mJ
1064 nm output energy	>2 mJ
532 nm pulse-width (FWHM)	5 nS
repetition rate	168 Hz
input energy to flashlamp	<10 J
refurbishing interval (excluding flashlamp)	>1000 hours

### 3. DISCUSSION OF RESULTS

#### 3.1 532 nm output

The 532 nm (frequency doubled) output using the angle-tuned CD\*A is shown in figure 2. The required 5 mJ of output is obtained for about 20 mJ of input to the frequency doubler and 5.5 J into the flashlamp. There is no evidence of saturation due to inadequate hold-off of the Q-switch up to 8 J of flashlamp input.

The pulse-width of the frequency doubled output varies with the energy being generated (figure 3). The pulse-width is within the specified limit from 5 mJ of output. The shortest pulse is achieved at the highest input energy and is 4 ns at an input of 8 J.

Analysis of recorded individual output pulses showed that the standard deviation of energy was less than 5% for output energies between 3 mJ and 8 mJ.

#### 3.2 1064 nm output

The 1064 nm (IR) output from the frequency doubler is a by-product which is used for detecting the water surface in the LADS application. The efficiency of the frequency doubler is such that more than 2 mJ of IR is available. The IR output at 168 Hz from the laser before the frequency doubler is shown in figure 4. The output increases monotonically with input up to the maximum level examined of 8 J when 32 mJ of IR output is obtained.

The variation in IR output with change in repetition rate was examined up to 250 Hz. The energy input to the flashlamp was set at a level which gives 5 mJ of frequency doubled output from the laser. Figure 5 shows that there is little variation in output up to 100 Hz. After 100 Hz there is a gradual and continuous decrease in output. The output at 168 Hz is 90% of the maximum.

### 4. COMPONENT LIFETIME

#### 4.1 Flashlamp lifetime

The definition of flashlamp lifetime varies with the manufacturer and end of life is usually given as when the light output decreases to some percentage of its original value. In the present case the end of life occurs if :-

- (a) Input energy to the flashlamp exceeds 10 J to produce the required frequency doubled output.
- (b) The flashlamp is difficult to strike.
- (c) The amplitude and timing jitter of the output is excessive.
- (d) The flashlamp breaks.

The manufacturer of the flashlamp recommends a maximum average power of 240 W/cm<sup>2</sup> for water cooled quartz flashlamps. A simmer current of 5 A is required to overcome problems of amplitude and timing jitter at high repetition rates. The simmer provides 300 W of the permitted 1500 W for the flashlamp, which means that a maximum input energy of 7.2 J at 168 Hz

should be applied.

A 1000 hour lifetest on the laser shows (figure 6) that input energy into the flashlamp (A), to produce 5 mJ of frequency-doubled output, had to be gradually increased so that after 400 hours the limit imposed by the maximum average power was approached. Operation at a higher power level, corresponding to 8 mJ, was then arranged with flashlamp (B) starting its lifetest at maximum average power, a flashlamp life of 160 hours was obtained. A third flashlamp, operated at the level which gave 5 mJ of frequency doubled output, completed the 1000 hour lifetest. Further tests would need to be conducted to determine whether these are typical lifetimes.

These results highlight a number of points:

- (a) A shorter, but probably adequate, flashlamp life can be obtained by starting operation at the maximum average power.
- (b) A flashlamp lifetime of at least 400 hours can be expected if operation is restricted to below 240 W/cm<sup>2</sup>.
- (c) The laser is capable of reliably producing 60% more output than the specification but with the disadvantage of a shorter flashlamp lifetime.
- (d) No component damage occurred during this lifetest which suggests that the component life (other than flashlamp) will be in excess of 1000 hours.

#### 4.2 Pump cavity

Experience has shown that a small circular cylindrical cavity is one of the most efficient methods of coupling energy from a flashlamp to a Nd:YAG laser rod, provided flashlamp and rod centres are equally spaced about the centre of the pump cavity. Silver as a reflective coating on the pump cavity is initially more efficient, but after about 20 hours of operation at 168 Hz the silver in the water filled cavity deteriorates. If evaporated gold is used this deterioration does not occur. The transfer efficiency of the gold surface is better than the silver surface after 20 hours. Lifetimes in excess of 1000 hours have been obtained using evaporated gold.

#### 4.3 Optical surfaces and components within the resonator

A 90% transmission output mirror is used on the resonator which results in the following:

- (a) The internal resonator power is kept to a minimum, thus reducing the probability of optical damage to components.
- (b) Because the output mirror overcouple the resonator, additional energy must be injected into the rod to obtain the required output, the resulting higher gain in the rod reduces the width of the output pulse.

Lifetesting at 60% higher than the specified output level has indicated that there are no likely problems with coatings on optical surfaces with this design of laser.



#### 4.4 Polariser

Figure 7 compares the relevant properties of polarisers that might be used in this laser. Experience with the Glan-Foucault polariser, used in the 1000 hour lifetest, has shown it to be a reliable device in this application. The MacNeille(ref.6) type of thin film polariser is preferred for its lower insertion loss which gives a 10% higher Q-switched output than the other polarisers.

#### 4.5 Pockels cell and quarter-wave plate

Conventionally the polariser and Pockels cell are used for Q-switching with a quarter-wave voltage applied to the Pockels cell during the period of hold-off. The problems associated with this Q-switching method are:

(a) After a period of time (about 100 hours) tracking occurs between the electrodes of the Pockels cell due to the migration of silver along the surface of the Pockels cell crystal. The consequent leakage eventually leads to Q-switching problems due to the inability of the Pockels cell to prevent lasing before it is required. The tracking and leakage can also cause a crack to develop in the crystal.

(b) When the laser is operated at high repetition rates, the combined effects of heating and a non-uniform applied voltage field in the Pockels cell produce induced birefringence, and breakthrough occurs. This breakthrough tends to set an upper limit to the maximum amount of laser output available.

The induced birefringence produced by the non-uniform electric field in the Pockels cell can be overcome by initially applying no field and using a quarter-wave plate to provide the hold-off. When Q-switching is desired, the voltage is applied to the Pockels cell which cancels the phase shift introduced by the quarter-wave plate. With this technique the maximum available output is increased by about 50% compared to conventional Q-switching. Also, since the quarter-wave voltage is only applied to the Pockels cell during the switching period the migration of electrode material along the Pockels cell crystal is significantly reduced and the life of the Pockels cell is increased.

#### 4.6 Pockels cell driver

The switch-time of the Pockels cell driver should be short or there is a broadening of the output pulse, switch-times of about 10 ns are found satisfactory in this application. A Pockels cell driver using a chain of avalanche transistors(ref.7) meets repetition rate, switch-time and life requirements. The switch-time of the output shown in figure 8 is approximately 5 ns. No deterioration of the driver is noticeable after  $4 \times 10^9$  switchings.

## 5. CONCLUSION

This report has shown that the laser discussed is capable of satisfying the requirements of the LADS specification. The configuration has been evaluated in the laboratory and has successfully completed a 1000 hour lifetest with no observable deterioration of laser components. In order to assess operational margins, the laser was used at an output level 60% higher than required. This necessitated running the flashlamp above the recommended maximum average power level. No serious problems were identified, however under these conditions flashlamp life is shortened thus requiring more frequent replacement.

Increasing the length of rod and flashlamp will overcome the average power limitation of the flashlamp with the added potential of operating at higher rates.

Although the laser discussed meets the specification and has completed a lifetest of 1000 hours, a slightly longer rod and flashlamp is recommended since the longer system would have a capability for higher output and repetition rates.

## 6. ACKNOWLEDGEMENTS

The assistance of C. Jones and G. Roberts in obtaining the results for this report is acknowledged.

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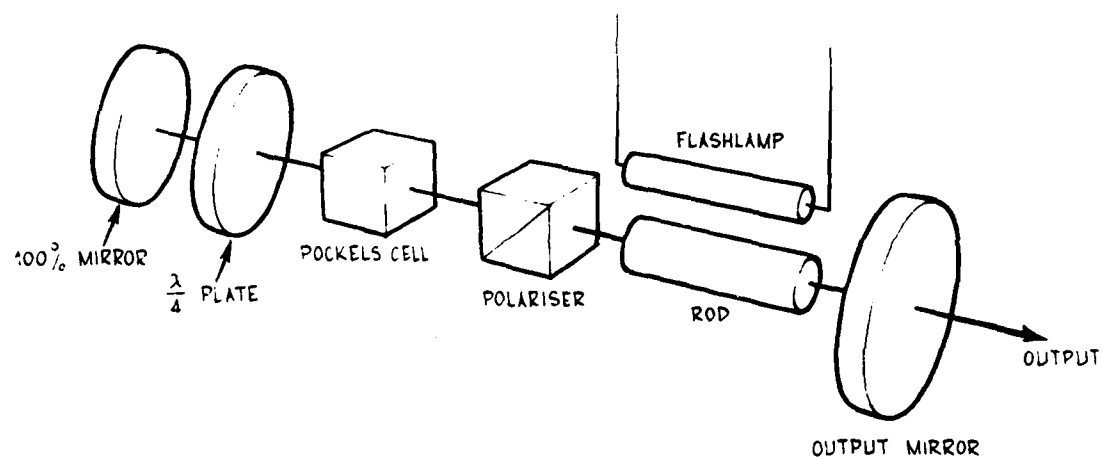


Figure 1. A schematic diagram of a conventional Q-switched laser

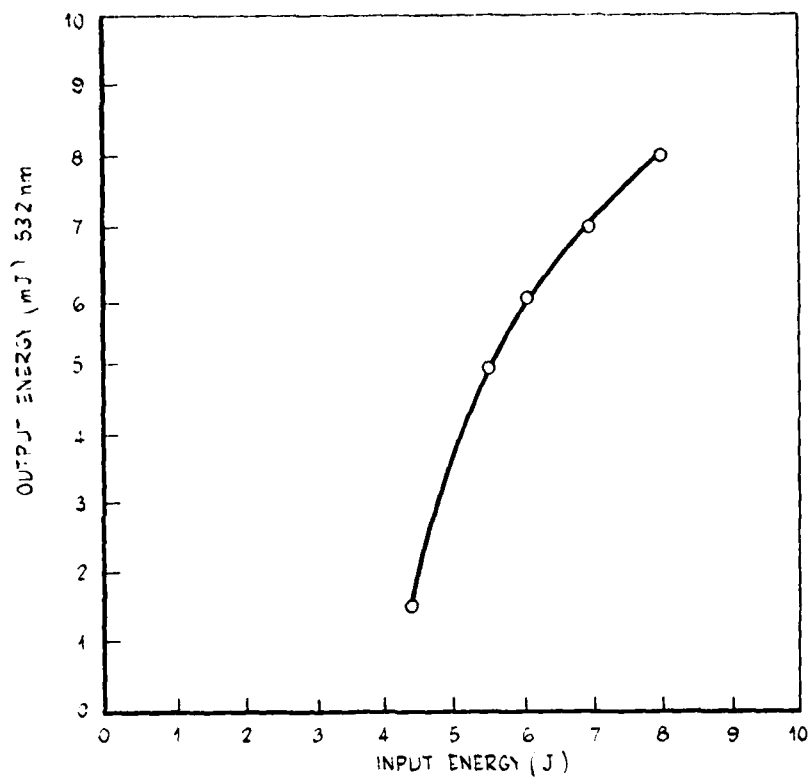


Figure 2. Change in 532 nm output with increasing input energy to flashlamp

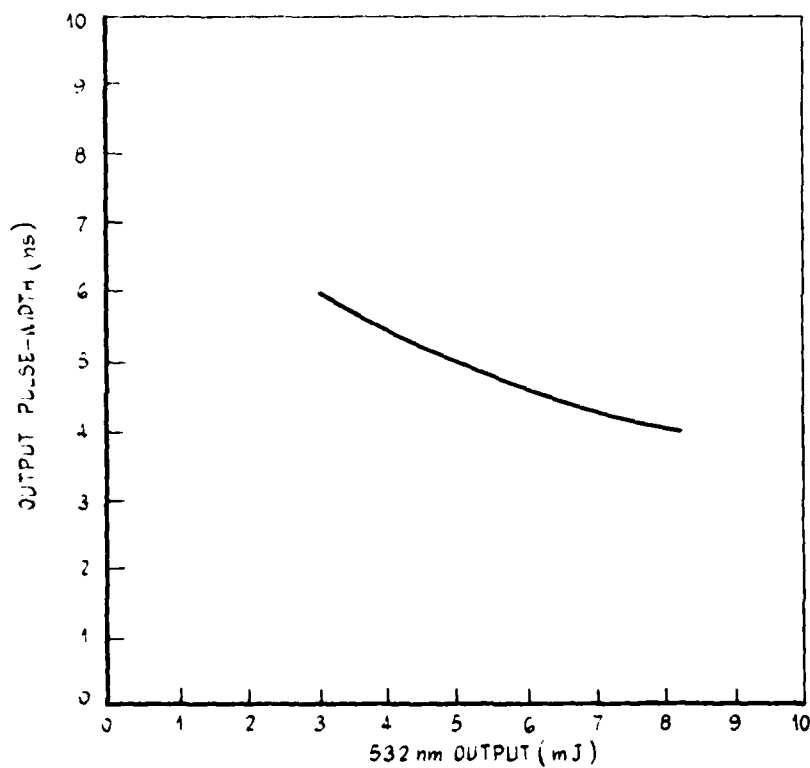


Figure 3. Change in 532 nm pulse-width with output energy

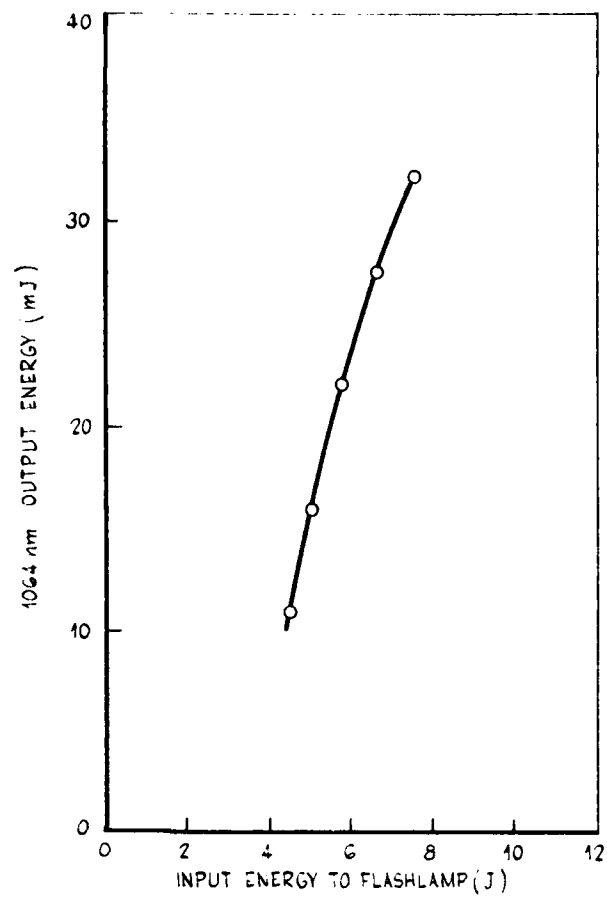


Figure 4. Variation of 1064 nm output with change of input energy to flashlamp

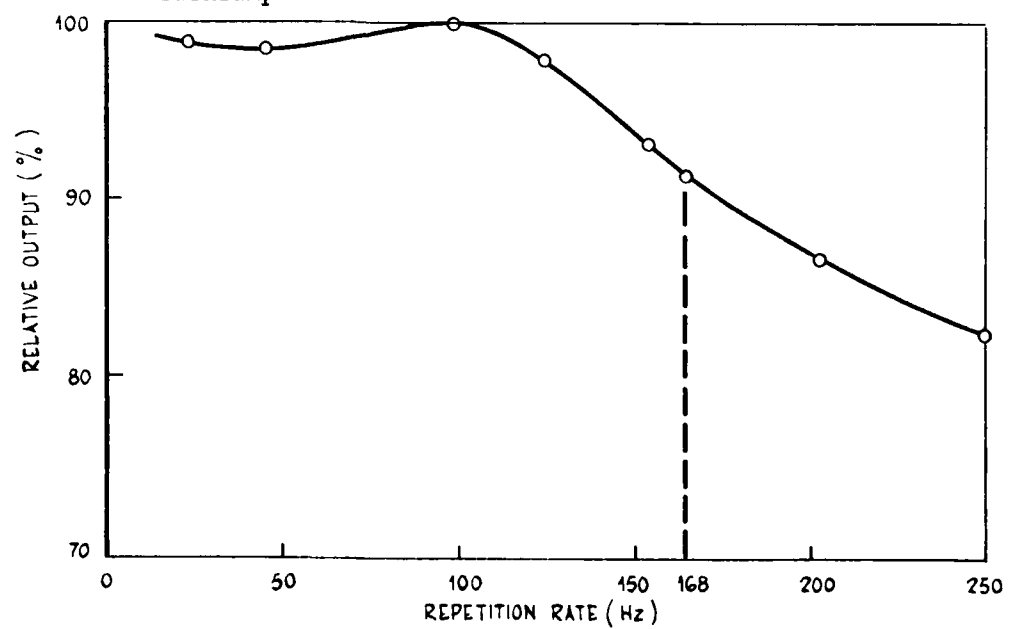


Figure 5. Effect of repetition rate on 1064 nm output

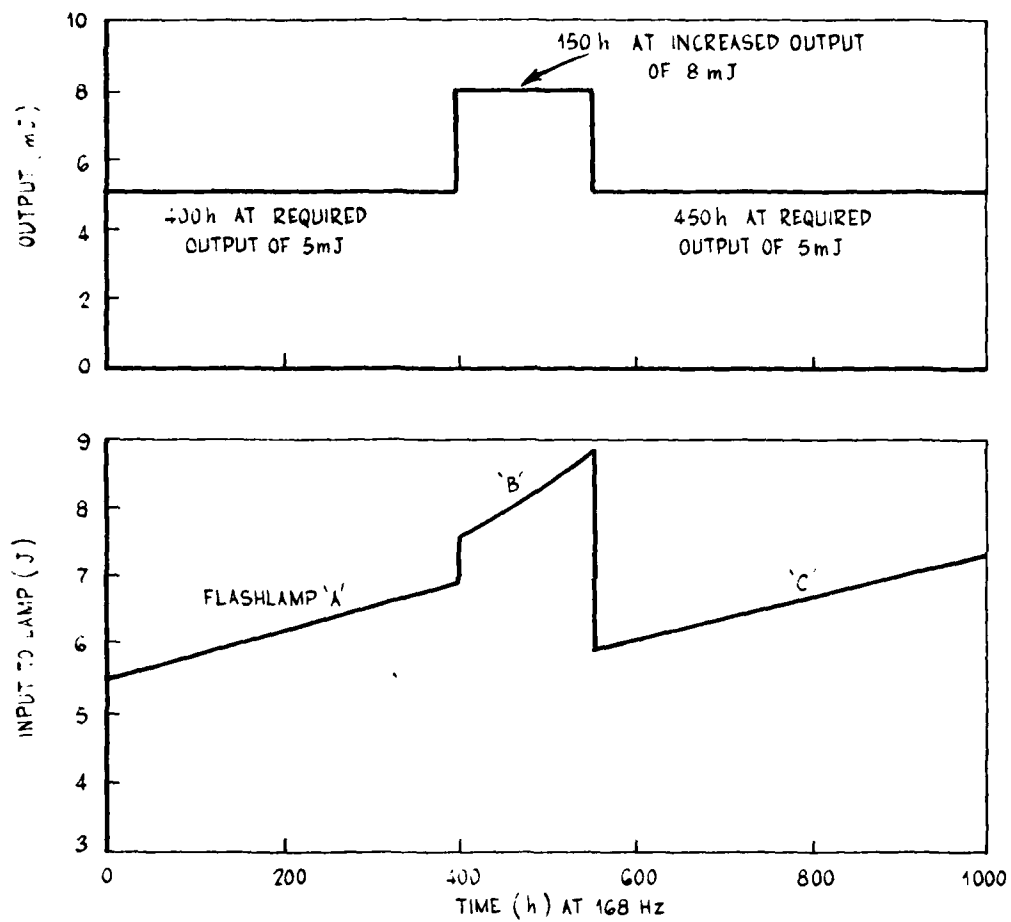
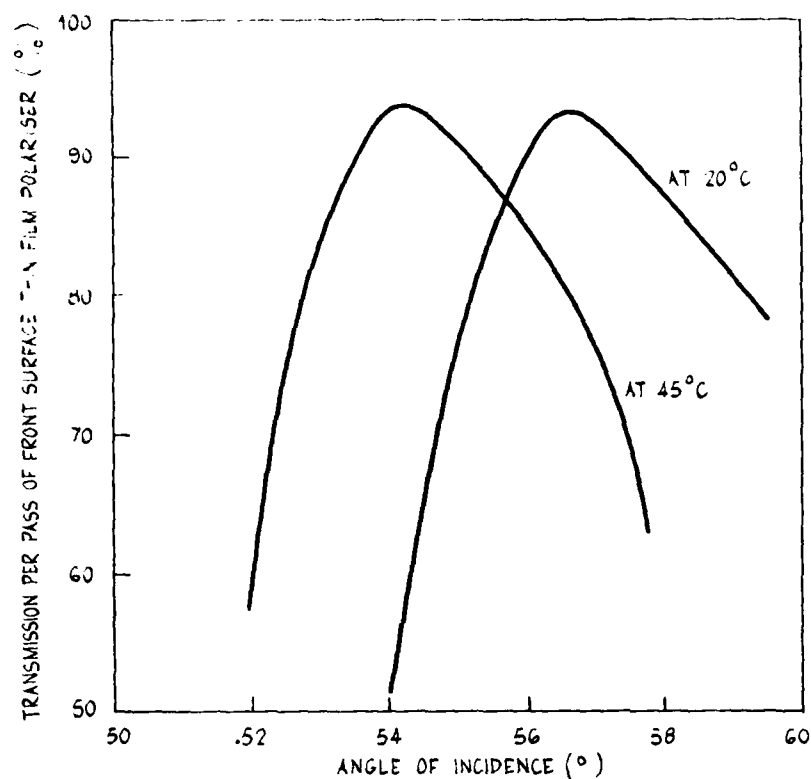


Figure 6. Laser lifetest at 168 Hz



Polariser	Claimed damage threshold	Field angle	Temperature sensitivity	Extinction ratio	Transmission	Beam displacement
Glan Foucault	200Mw/cm <sup>2</sup>	> 3°	Nil	5 x 10 <sup>-5</sup>	97%	< 3 mm of ARC
Front Surface Thin Film	400Mw/cm <sup>2</sup>	± 15 min	See above curve	4 x 10 <sup>-3</sup>	94%	2.4 mm
MacNeille type Thin Film	300Mw/cm <sup>2</sup>	± 18 min	Nil	2.5 x 10 <sup>-3</sup>	98.6%	< 20 s ARC

Figure 7. Comparison of polarisers suitable for Q-switched Nd:YAG lasers



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Figure 8

X2000 Probe attached to output  
Response time  $< 1$  ns

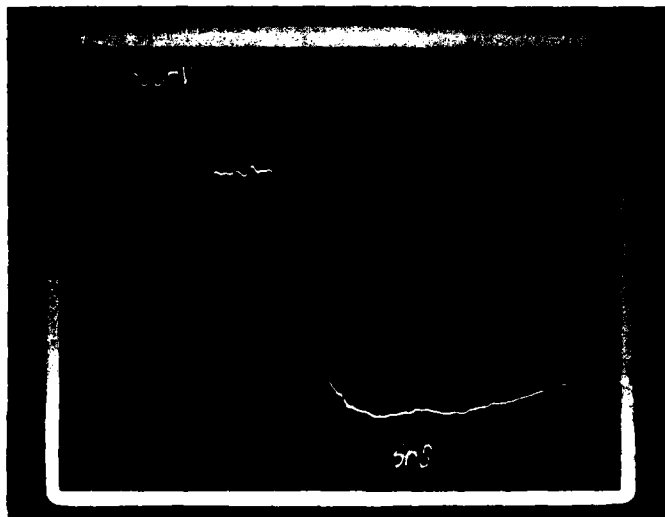


Figure 8. Switching characteristics of Pockels cell driver

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